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AUTHOR Chan, Carol; Bereiter, Carl
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ABSTRACT

This study examined students' active roles in constructing knowledge when learning new information in the domain of biological evolution. A computer-based connectionist methodology was developed to provide a way to present students with new information while the experimenter provides probe statements congruent with or contradictory to the student's beliefs. Fifty-four students in grade 9 and 54 students in grade 12 each participated in 1 of the following 4 conditions: (1) individual-assimilation; (2) individual-conflict; (3) peer-assimilation; and (4) peer-conflict. Pretests and posttests and protocol analysis identified knowledge changes and knowledge processing activity. Path analysis suggested that only strategy exerts a strong direct effect on conceptual change and mediates the effects of age, prior knowledge, and conflict. Protocol analysis showed that students using a direct assimilation approach could use different strategies to assimilate contradictory information even though it represented something quite different from what they believed. The peer interaction condition did not produce significant effects in fostering conceptual change, although there were indications that group effects on conceptual change were greater for older students in the conflict condition. A table showing hypothetical inputs representing students' beliefs in each of the four conceptions and the corresponding weight activations generated by the network is appended, and five figures illustrate student processing. A 26-item list of references is included. (SLD)

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Effects of conflict and knowledge-processing strategy on conceptual change

Carol Chan and Carl Bereiter
Centre for Applied Cognitive Science
The Ontario Institute for Studies in Education

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Effects of conflict and knowledge-processing strategy on conceptual change

A common approach to fostering conceptual change is to confront students with contradictory information (Nussbaum & Novick, 1982; Posner, Strike, Hewson, & Gertzog, 1982; West & Pines, 1985). Thus far, equivocal results have been obtained (Burbules & Linn, 1988; Champagne, Gunstone, & Klopfer, 1985; Eylon & Linn, 1988). Increased attention has lately been given to the importance of inquiry frame (Perkins & Simmons, 1988), belief revision (Kuhn, 1989; Schauble, 1990), self-regulated learning (Anderson & Roth, 1989), and explanation (Ohlsson, 1991) in science learning. If knowledge is actively constructed by learners (Bereiter, 1985; Brown, 1988; Resnick, 1987; Wittrock, 1974), contradictory information that is merely presented would be of limited use unless students actively process the new information and integrate it with their existing knowledge.

This study examined students' active role in constructing knowledge when learning from new information in the domain of biological evolution. The first objective was to examine knowledge-processing activity students engage in when they are processing new information. Previous studies on intentional learning have shown that knowledge-building goals (Ng & Bereiter, 1991), and constructive activity (Chan, Burtis, Scardamalia, & Bereiter, 1992) contribute to learning with consistency across domains (Ogilvie & Bereiter, 1989). Average learners tend to assimilate or fit new information directly into existing knowledge whereas expert learners employ a knowledge-building approach to transform their knowledge (Bereiter & Scardamalia, 1989). This study examined whether the hypothesized approaches of direct assimilation and knowledge-building lead to differences in conceptual change.

The second objective was to test the effects of conflict on conceptual change by comparing a condition in which information was ordered so as to maximize conflict with each student's expressed belief versus a condition in which the ordering minimized conflict. It was predicted that the more conflictual condition would produce more conceptual change, but that these effects would be mediated through knowledge-processing strategy effects.

A related objective was to examine the role of peer collaboration on conceptual change. The idea of situated cognition and collaborative learning is now widely accepted. There is also evidence that peer collaboration facilities learning and conceptual change (Brown, Collins, & Duguid, 1989; Forman & Cazden, 1985; Newman, Griffin, & Cole, 1989; Rochelle, in press). It was hypothesized that students in group problem-solving contexts would be better able to recognize conflict and would be more likely to halt assimilation and engage in knowledge-building.

Method

Test materials: A connectionist methodology to confronting students with new information

Identifying naive conceptions A questionnaire consisting of 52 statements representing students' conceptions and misconceptions of evolution was administered to about 200 high-school students from grades 9 to 13. The questionnaire was constructed based on open-ended responses and field-tested with students and biology teachers. Students were asked to indicate whether they agree or disagree with the statements on a 5-point scale. Factor analysis on the responses yielded a four-factor solution representing students' conceptions: (1) Purpose, (2) Battle, (3) Environmental Change, and (4) Darwinism. Pearson correlations of gender and age with each of the factor scores were computed. The results showed that gender differences did not exist. Age was found to correlate positively with Environmental Change (.32, $p<.01$), and negatively with Battle (-.20, $p<.05$).

Confronting prior conceptions with new information A computer-based connectionist methodology (Rumelhart & McClelland, 1986) was developed to provide a principled way to present students with new information at different degrees of discrepancy from their existing beliefs. Selected items from the factor-analytic study were given a set of weighted connections to each other and to the identified factors. Three groups of units were included: (a) 4 factor-statement units (b) 8 specific-statement units, and (c) 8 probe-statement units (Figure 1). In the experiment, the student was asked to rate the four 'factor' statements by indicating how strongly they agree or disagree with them. These ratings were used as inputs to a competitive activation network where outputs were the activation levels of a set of 8 scientifically valid statements about evolution (probe statements). The more positive the activation level of a statement, the more compatible it was assumed to be with the student's position; the more negative the activation level, the more incompatible. As the network was activated, the student's pattern of agreement or disagreement to the factor statements could be used to identify whether he or she would agree or disagree with the remaining statements. Accordingly, the experimenter could systematically provide the student with probe statements which were congruent or contradictory to his or her beliefs.

Testing and fine-tuning of the connectionist network were carried out to select the most appropriate statements from the pool of items. It was predicted that a high input to the factor unit would lead to high positive activations of the specific-item units and high negative activations of the probe-item units representing the corresponding conception. Comparison of the activation patterns of the resultant network suggested that the prediction of the responses was adequate (Appendix). For example, a high input to the purpose factor representing a 'purpose' misconception resulted in highest negative activations on the anti-purpose probe statements.

Subjects

54 students from grade 9 and the same number from grade 12 participated in the experiment. Students typically had no formal instruction on evolution since it is a curriculum unit taught to OAC (grade 13) biology students in the last semester. A belief question was administered and students holding a creationist view were not included in the study.

Condition

Students were randomly assigned to one of the four conditions: (a) individual-assimilation, (b) individual-conflict, (c) peer-assimilation, and (d) peer-conflict. In the conflict condition, students were presented with the probe statement which was maximally contradictory to their conceptions followed by incrementally less discrepant ones. In the assimilation condition, the maximally congruent probe statement was first presented, followed by incrementally less congruent ones. In the peer-interaction condition, two students of the same grade level worked together to negotiate their understanding of evolution and students worked on their own in the individual condition.

Procedure

Pretest Students were individually interviewed by an experimenter and asked to (a) indicate whether they think the evolution theory has been proved wrong, (b) tell what they know about evolution, (c) indicate whether they agree or disagree with 8 specific statements about evolution, and (d) rate the relative importance of 4 factor statements in explaining evolution. Students in the peer condition were interviewed individually for the first three tasks, and they worked together to decide on the ratings for the factor statements.

Test Eight probe statements which varied at different degrees from students' expressed beliefs were presented, one at a time. Student's ratings of the four factor statements were used to activate the network. When the program was run, the connectionist network provided activation weights indicating which of the probe statements the student would tend to agree or disagree with. Depending on the condition, the students were then provided with the maximally congruent or the maximally contradictory probe statement and asked to think aloud about the new information. They were then asked to re-rate the 4 factor statements. Students in the peer condition were asked to discuss the probe statements and jointly decided on any changes in ratings. For any changes that were made, new ratings were entered to the network, which would then provide activations for the next probe statement. If no changes were made, the next maximally discrepant or maximally congruent probe statement was provided.

Students' verbalizations were tape-recorded for subsequent analysis of knowledge-processing strategy.

Posttest Students' posttest learning was assessed by asking them to (a) finalize the ratings of the 4 factor statements, (b) summarize their new understanding, (c) tell what else they need to know to advance their understanding of evolution, (d) answer two application questions: explain how ducks evolved webbed feet and why insecticides were no longer useful after repeated use, and (e) rerate the 8 specific-item statements.

Measures

Knowledge-processing activity

The method of protocol analysis used in this study has been employed in a number of previous studies (Scardamalia & Bereiter, 1984; Chan, Burtis, Scardamalia, & Bereiter, 1992) for examining prototypical patterns of cognitive activity when students were thinking-aloud while learning from texts. Protocol analysis suggested that different types of knowledge-processing activity could be identified as illustrated in the examples below:

Probe statement. An animals cannot evolve by adapting to its environment. It is the environment which select the well-adapted animals. A deer cannot choose to evolve long legs although long legs are important for survival. Some deer, however, may be born with longer legs which allow them to run faster. These individuals have a better chance of surviving and leaving more offspring.

(1) Off-text sub-assimilation moves Students give associative responses remotely related to the text information cued by isolated words, phrases, or fragmentary parts of the probe statement.

I think the smaller you are, the faster you can go, like your strides are smaller, but you can go really fast, cause the rabbit is really small, and they can go really fast. Giraffes have long legs and they have to take bigger strides to keep their pace going. I know because I am tall, I have to take bigger strides, and it slows me down. But I think the smaller the animal, the faster they can go.

(2) Direct assimilation moves Students fit new information directly into existing knowledge by (a) rejecting new information and retelling what they already know, (b) distorting new information to fit with existing beliefs, or (c) making ad-hoc rationalizations to minimize the difference between beliefs and new information

> Stonewalling. Students reject new information without understanding what the new information says, and tell what they already know.

It says that an animal cannot evolve by adapting to its environments. I don't agree with that because they are adapting to their environments. The squirrels and everything you see in the street, they are cautious about crossing the street. Of course, they have adapted to the environment and they have to. They must have done it for years now, and pass it onto their offspring.

> Distortion. Students agree with the text even if it is contradictory to their beliefs by giving selective attention to salient features which are consistent with their conceptions; immediate interpretations are made conflating information with beliefs, and text is distorted to fit with their conceptions.

I agree with that because you can't help the way that you are born, and if you are born with something else, then you just have to use it the way that it was meant to be used.

I think this is correct. It is true that an animal cannot choose to adapt itself to the environment, the environment has to adapt to you basically. The environment has to be suitable for you in order to live.

> Patching. Students accept new information at face value, and patch the differences by ad-hoc rationalizations.

I guess it is pretty true. I forgot to think about that. That if an animal can't survive it will move to a new environment where it can. Because I just realized that if a polar bear lived in the tropics, or a deer lived on an ice cap, they'd try to get to colder and warmer climates respectively

(3) Surface-constructive moves. Students seem to show some understanding of what the text says. There is no indication of distortion or misunderstanding but the implications of new information are not considered.

> Paraphrases. Students give simple paraphrases and inferences of the new information without reconsidering their beliefs.

I guess longer legs help reproduction, because they run faster, they survive and leave more offspring. It is not the deer's choice whether it has long legs or not, it just happens.

> Juxtaposition. Students recognize the discrepancy between their naive conceptions and the text, but the inconsistency is minimized by juxtaposing correct and incorrect information, or by using an exception strategy.

What this tells me is that these things happen by chance, that they may be born with longer legs and this just happens by chance, but I don't consider it

too valid. Because it happens in some instances, but not in all. So, of course, those ones with longer legs could survive better

(4) Implicit knowledge-building moves Students consider new information as something that is problematic which needs to be explained. New information is not prematurely assimilated but is held and examined for its implications for their existing beliefs : (a) identify 'what needs to be explained' in explanation-driven enquiry, (b) reconsider beliefs and treat knowledge as an object for enquiry, (c) go beyond text information to construct a global principle for the domain in question.

I don't know about the leave more offspring, but they probably have a better chance of surviving because they can outrun their predators. But an animal can't evolve by adapting ? How did the deer get the long legs in the first place? Something must have told them to grow long legs, so in a sense, it is adapting to its environment. Or, if it was just made with long legs in the beginning, then it must have evolved into something with long legs in the first place. So, it is adapting to its environment, but there is something missing, but not all animals adapt to their environments, so the one that can adapt more readily to the environments are the ones most likely to survive, considering that they can fight off the predators and things like that, but I don't think that it's true in all cases, because, I guess "it's the environment that selects -- if they are well adapted to any environment, then they really don't have to change or adapt, 'cause they are already adapted to it..like African killer bees, they are already adapted to the environment, but they are a superior species of bees, so they can survive better here and they can survive as well there. It can't choose to evolve long legs, but some may be born with long legs, so maybe there's some change occurring in the deer. The way it is at birth is the way it is going to be for the rest of its life. But the way a deer evolves might not be in its lifetime, but in the lifetime of its offspring.

(5) Explicit knowledge-building moves Students indicate deliberate moves to halt immediate interpretation, to accumulate new information, and to make connections among different pieces of information.

Normally, I would move environment up and lower needs and purpose, because this statement says, OK, it is not needs and purposes that determine the flow of evolution. But I am not going to do that yet, until I find something that explicitly states that needs and purposes have nothing to do with evolution.

It seems like the cards contradict themselves because it happens by chance that things will change but things haven't happened.....This card seems out of the place from the others. I'm trying to piece things together into one whole, to find a connection. Right now I'm trying to think about how everything can connect because I have to keep in mind all the other cards I have seen, and the ones, I have to keep in mind, the fact that it occurs mostly by chance. I keep looking at these ones down here but this one is the

main one, so it seems like the others are less important, but we still have to give them proper standing, because it still does matter. It's all a part of it.

Students' verbalizations for each statement were rated on a 5-point scale and a mean score was produced for knowledge-processing strategy.

Prior Knowledge

Knowledge activation (qualitative) A 3-point scale was developed for rating students' verbalizations of what they know about evolution. Responses showing intuition conceptions were rated 1, responses showing some understanding of genetics were rated 2, and responses showing the Darwinian conception were rated 3.

Pretest Item-score and Factor-score (quantitative) Students were asked to indicate on a 11-point scale whether they agree or disagree with 8 specific item statements representing the 4 major conceptions. They were also asked to rate on a 11-point scale the relative importance of 4 factor statements in explaining evolution.

Conceptual Change

Knowledge Quality Four different measures of deep-learning were developed to tap students' understanding of evolution.

Summary. A 5-point scale was used for rating posttest summary. Responses restating naive conceptions were rated 1; responses showing the recall of trivial facts were rated 2; responses showing the incorrect assimilation of new information were rated 3; responses showing the emergence of new conceptions were rated 4; and responses showing a Darwinian conception were rated 5.

New questions. A 5-point scale was used for rating posttest 'don't know' questions. Off-task comments and non-responses were rated 1. Questions on text-unrelated information were rated 2; questions on text-related information were rated 3; questions indicating the recognition of a discrepancy between personal knowledge and text information were rated 4; and questions which involve elaboration of the problem or attempts to resolve the discrepancy were rated 5.

Application questions. A 5-point scale was used for rating the application questions. Responses which were irrelevant were rated 1, responses showing the existing naive conceptions were rated 2, responses showing the incorrect assimilation of new information were rated 3, responses showing coexisting correct and incorrect conceptions were rated 4, and responses showing the correct application of the principle of 'natural selection' were rated 5.

Belief Change

Posttest item-score and factor-score. Ratings of the item score were obtained at pretest and posttest, and ratings of the factor score were obtained at pre-posttests, as well as on each occasion when students were presented with a probe statement. Ratings from three experts were obtained to provide a criterion measure for comparing students' beliefs with experts' beliefs. The ratings of the three experts were averaged and correlations with each student's ratings were computed. A high positive correlation indicates resemblance to the experts' belief which is assumed to represent the scientific conception.

Results

Developmental differences in knowledge-processing strategy

To examine the overall developmental effects, ratings across the statements were pooled to produce an average score called knowledge-processing activity. Figure 2 shows the mean knowledge-processing ratings for students in the four conditions for the two grades. Three way ANOVA on the knowledge-processing ratings (grade x group x condition) showed a significant main effect for grade ($F = 5.69$, $p<.05$), and for condition ($F= 21.1$, $p<.01$). Since no group effects were obtained, scores across the two groups were collapsed for analysis.

Further analyses were carried out to examine developmental differences for each level of knowledge-processing ratings. Due to the small number of level one and level five responses, they were collapsed with the adjacent levels, resulting in three major levels: (a) direct-assimilation moves, (b) surface-constructive moves, and (c) knowledge-building moves. ANOVA on assimilatory moves showed a significant grade effect ($F = 4.31$, $p<.05$) favoring the younger students, and ANOVA on knowledge-building moves showed a near-significant effect for grade ($F = 3.14$, $p= 0.08$) favoring the older students.

Conflict and conceptual change

Differences in knowledge-quality between conflict and assimilation To simplify the presentation of results and to obtain a more reliable measure, the four posttest qualitative measures were combined to produce a single composite score, called Knowledge Quality. The first principal component accounted for 55% of the variance and the loadings were as follows: summary 0.80, wonderment 0.70, near-application 0.71, and far-application 0.75. Analysis of variance on the knowledge-quality score resulted in a significant condition effect ($F = 7.78$, $p<.01$), and an interaction effect of condition by grade ($F= 4.19$, $p<.05$) favoring the conflict group. MANOVA analyses on each of the individual scores gave the following results :

Significant condition effects were obtained for summary ($F = 5.72$, $p<.05$), wonderment ($F = 3.46$, $p=0.06$), and far-application ($F= 7.21$, $p<.01$), favoring the conflict group. Interaction effects of condition by grade were also obtained for summary ($F= 4.09$, $p<.05$), and near-application ($F=6.01$, $p<.05$).

Differences in belief-change between conflict and assimilation Figure 3 shows the profile of changes of the factor-scores with each successive presentation of the probe statements for the two groups. Analysis of covariance was carried out on the posttest factor scores controlling for the effects of pretest factor scores. A significant main effect for condition ($F = 16.5$, $p <.01$), and an interaction effect of group by condition ($F = 4.25$, $p <.05$) were obtained, favoring the conflict group. ANCOVA on item scores also showed a significant condition effect ($F = 5.14$, $p <.05$) favoring the conflict group.

Differences in knowledge-processing activity between conflict and assimilation Analysis of variance on the mean knowledge-processing ratings resulted in a significant condition effect ($F = 21.1$, $p<.01$), favoring the conflict group. Analysis on each of the three categories gave the following results : Significant condition effects were obtained for direct-assimilation moves ($F = 22.9$, $p<.01$) favoring the assimilation group, and for knowledge-building moves ($F = 13.9$, $p<.01$) favoring the conflict group (Figure 4).

Peer interaction and conceptual change

Peer-interaction and knowledge-processing activity The mean ratings of knowledge-processing activity were 2.65 for the individual condition and 2.78 for the peer condition. Although there was a trend difference, ANOVA yielded no significant group effects. Further analyses showed significant group effects for assimilatory moves ($F= 4.76$, $p<.05$) with higher means for the individual group, and group effects for surface-constructive moves ($F= 8.58$, $p<.01$) favoring the peer group.

Peer-interaction and conceptual change For the posttest knowledge-quality scores and belief-change scores, no main effects were obtained. Further analysis showed that a significant interaction effect of group by grade was obtained for summary ($F=5.34$, $p<.05$), and a near-significant group by grade effect for near-application ($F=2.98$, $p=.08$). Additionally, there was an interaction effect of condition by group ($F = 4.25$, $p< .05$) for factor scores.

Prior knowledge, conflict, knowledge-processing strategy and conceptual change

Three measures of prior knowledge were obtained which included (a) knowledge activation, (b) pretest factor scores, and (c) pretest item scores. The three measures were combined to produce a single composite score, called Prior Knowledge. The first principal component accounted for 57 % of the variance with the following loadings: knowledge activation 0.84,

factor score, 0.64, and item score 0.77. ANOVA on prior knowledge showed no significant effects for grade, group, or condition.

To examine whether knowledge-processing strategy predicted conceptual change over and above prior knowledge and condition effects, a multiple regression analysis was carried out, with grade entered first, followed by prior knowledge, followed by condition, and followed by knowledge-processing strategy. The results (Table 1) suggested that while prior knowledge contributed to knowledge quality, conflict was a significant contributor to conceptual change, with prior knowledge held constant; and knowledge-processing activity was a significant contributor over and above prior knowledge and conflict.

Table 1 Multiple Regression Analysis of Grade, Prior Knowledge, Condition, and Knowledge-Processing Strategy on Posttest Knowledge-quality

	R	R^2	R^2 Change	F
Grade	.13	.02	.02	1.74
Prior Knowledge	.36	.13	.12	7.97**
Condition(conflict)	.44	.19	.06	8.20**
Knowledge-processing moves	.69	.48	.29	24.12**

Path Analysis

A path analysis was carried out to obtain a more coherent picture of the possible causal relationships among grade, prior knowledge, conflict, knowledge-processing strategy, and conceptual change. Two measures of conceptual change were included : (a) belief-change measured by gains in item-ratings from pretest to posttest, and (b) knowledge-quality measured by posttest deep-learning questions (Figure 5). Path coefficients based on standardized regression weights showed that grade, prior knowledge, and conflict all affected knowledge-processing activity (.24, .31, .38 respectively, $p<.01$) which in turn affected belief change (.57, $p<.01$) and knowledge-quality (.64, $p<.01$). A negative path from prior knowledge to belief-change suggested that high-knowledge students obtained less gains in item-ratings, which is probably due to an artifactual effect of high pretest scores. For the other measure which did not involve gain scores, path coefficients showed that the direct path from prior knowledge to posttest knowledge-quality was small and insignificant. Additionally, the direct paths from grade and conflict to belief-change and knowledge-quality were both small and insignificant. These findings suggested that the effects of grade, prior knowledge, and conflict on conceptual change were primarily mediated through knowledge-processing activity.

Discussion

This study aimed to examine students' knowledge-processing strategy and changes in their naive conceptions when they are presented with scientific

information. Previous studies have provided indirect evidence of assimilation (Driver & Easley, 1978; Vosniadou & Brewer, 1987), and characterizations of self-regulatory learning in science (Anderson & Roth, 1989). This study more specifically examined the hypothesized approaches of direct-assimilation and knowledge-building. Certain themes seem to emerge characterizing learning in a difficult domain which involves conceptual change. In accordance with the distinction between direct assimilation and knowledge-building, one strategy for knowledge-building is to avoid premature assimilation of new information to existing concepts. Typically, low-performing students tended to assimilate or fit new information into existing concepts. Different coping strategies were used such as ignoring or distorting new information to fit with existing schemas, or using ad-hoc repair strategies to patch the differences such that only minimal belief revision is required. On the contrary, instead of fitting information with what they already know, the high-performing students recognized that the new information present problems that need to be dealt with. Inconsistency between one's belief and new information was identified and attempts were made to explain how evolution works. There were also indications that students would halt immediate interpretations and accumulate/connect different pieces of new information to construct their domain understanding.

Previous studies using the contradiction paradigm have shown equivocal findings. This study employed a connectionist methodology to present information which systematically varied from what students believed. Although prior knowledge and conflict both contribute to learning, a path analysis suggested that only strategy exerts a strong direct effect on conceptual change and mediates the effects of age, prior knowledge, and conflict. Protocol analyses showed that students using a direct assimilation approach could use different coping strategies to assimilate contradictory information even though it represented something quite different from what they believed. Contradiction of students' naive conceptions is effective only when students are actively mobilizing knowledge-building strategy to make sense of the new information in relation to their beliefs.

The peer interaction condition did not produce significant effects in fostering conceptual change although there were indications that group effects on conceptual change were greater for older students in the conflict condition. It seems plausible that the effects of peer interaction vary in different learning situations and are maximized in conflictual situations. Observations also suggested that the older students were more skilled in engaging in negotiations whereas younger students tended to work alongside each other without actually engaging in productive discourse. Previous works have shown the importance of conversational exchange in fostering conceptual change. Qualitative analysis of peer-interaction protocols suggested that students might be engaged in different kinds of discourse patterns. Analyses examining the dynamics of collaborative knowledge-building are currently being carried out.

It is now widely accepted that students play an active role in their own learning. This study extended previous works examining students' self-regulatory learning in a domain where they have limited prior knowledge. Assimilation of new information to what one already knows minimizes opportunity for belief revision. Conceptual change involves reconsideration of existing beliefs in light of new information, in order to reach new understanding. Conflict could trigger the knowledge-building process when students view their knowledge as problematic. There is a need to go beyond identifying and contradicting students' naive conceptions to fostering their ability to take charge of their own knowledge-building.

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Appendix _ Hypothetical Inputs Representing Students' Beliefs in Each of the Four Conceptions and the Corresponding Weight Activations Generated by the Network

(1) Purpose

Inputs	Factor Statements		Specific Statements		Probe Statements	
+1	HP	83	P1	48	CP1	-51
			P2	51	CP2	-47
					CPE	-53
					AP	39
-1	HB	-78	B1	24	CB1	20
			B2	25	CB2	-10
-1	HE	-76	E1	40	CE1	-34
			E2	44	CE2	3
-1	HD	-79	D1	-29		
			D2	-7		

(2) Battle

-1	HP	-80	P1	5	CP1	19
			P2	-3	CP2	4
					CPE	27
					AP	-7
+1	HB	82	B1	43	CB1	-35
			B2	39	CB2	-33
-1	HE	-80	E1	-2	CE1	-20
			E2	7	CE2	-6
-1	HD	-77	D1	27		
			D2	34		

(3) Environmental Change

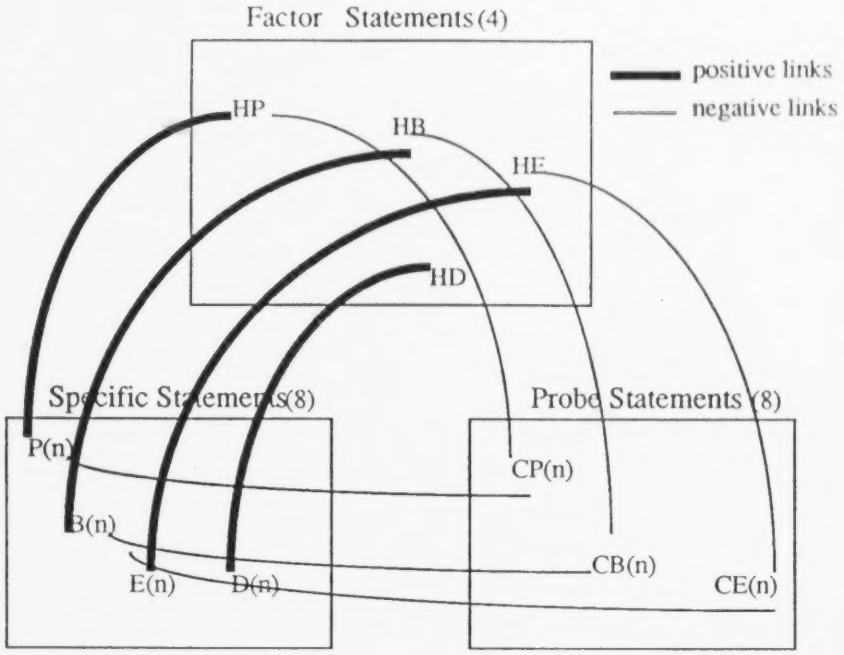
	Factor Statements		Specific Statements		Probe Statements	
-1	HP	-76	P1	38	CP1	-17
			P2	29	CP2	-28
					CPE	-41
					AP	10
-1	HB	-79	B1	5	CB1	16
			B2	21	CB2	18
+1	HE	82	E1	49	CE1	-45
			E2	47	CE2	-34
-1	HD	-79	D1	-23		
			D2	-13		

(4) Darwinism

-1	HP	-83	P1	-44	CP1	47
			P2	-39	CP2	43
					CPE	55
					AP	-27
-1	HB	-80	B1	10	CB1	29
			B2	-6	CB2	19
-1	HE	-81	E1	-30	CE1	15
			E2	-13	CE2	26
+1	HD	84	D1	59		
			D2	57		

Factor statements: HP, HB, HE, HD
Specific statements: P1, P2, B1, B2, E1, E2, D1, D2
Probe statements: CP1, CP2, CPE, AP, CB1, CB2, CE1, CE2

Figure 1 Connections among units representing students' conceptions and new information in the connectionist network



Factor-statement units: General and explicit statements representing students' conceptions about evolution

HP: Evolution is directed by needs and purposes of animal species
HB: Evolution is a battle of stronger species killing off weaker ones
HE: Evolution depends on changes which occur in the environment
HD: Evolution depends on changes which first occur by chance

Specific-statement units Specific statements representing the four different conceptions

P1 : Animals do not change unnecessarily. They only change when needs arise.
B1 : Every animal has natural enemies and eventually one wins and the other loses. This is how evolution works
E1 : In order for evolution to take place, some changes must occur in the physical environment of animals.
D1 : New characteristics first appear due to accidental changes in the genetic materials of animal.

Probe-statement units : scientifically-valid statements which contradict the identified naive conceptions

CP1 : An animal cannot evolve by adapting to its environment. It is the environment which selects the well-adapted animals. A deer cannot choose to evolve long legs although long legs are important for survival. Some deer, however, may be born with long legs which allow them to run faster. These individuals have a better chance of surviving and leaving more offspring.

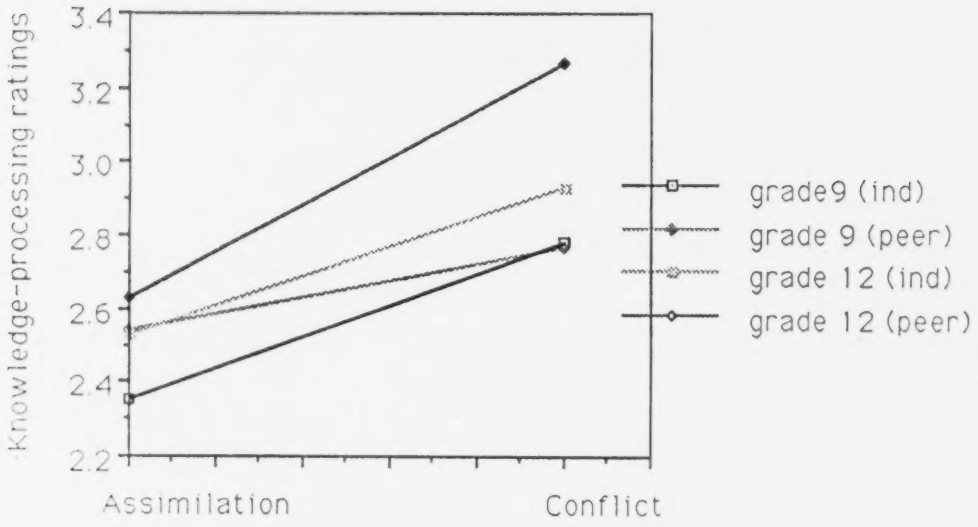


Figure 2 Mean knowledge-processing ratings for group (individual and peer), grade (9 and 12), and condition (assimilation and conflict)

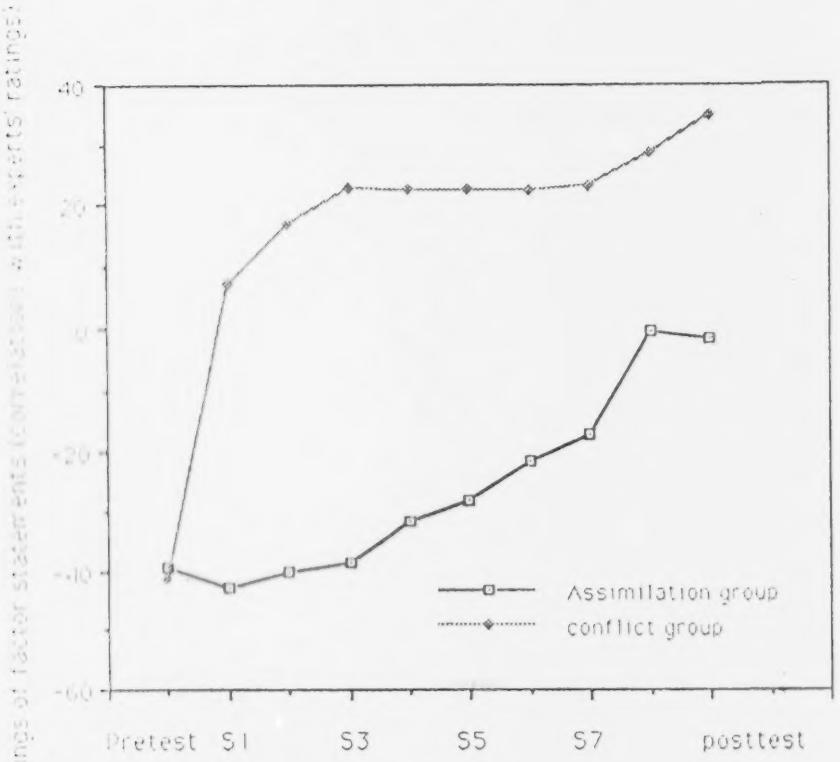


Figure 3 Profile changes of factor statement ratings for assimilation and conflict

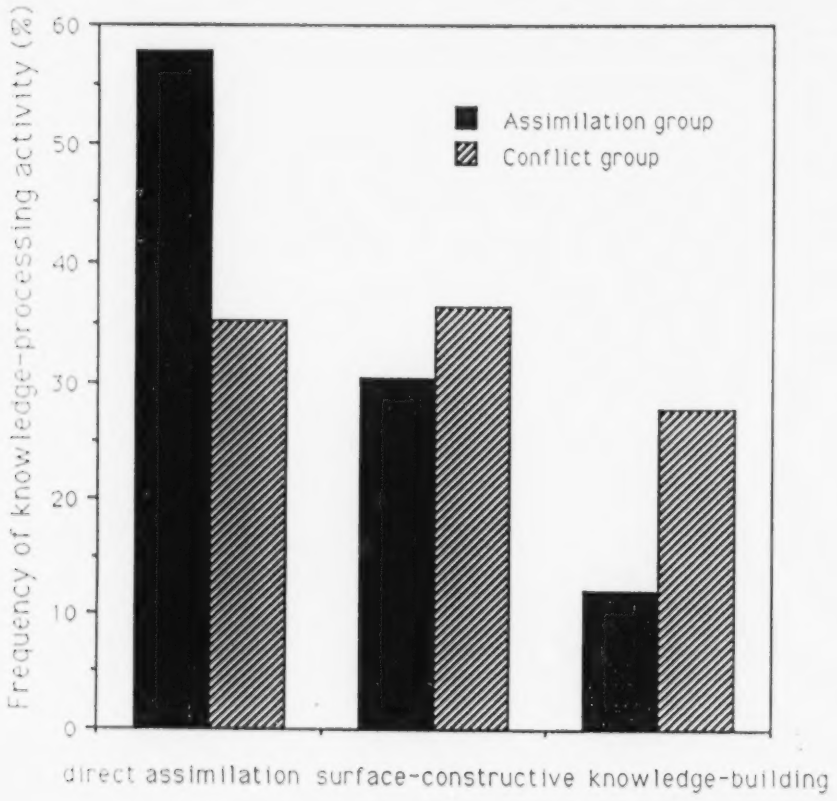


Figure 4 Distribution of direct-assimilation (level 1 & 2), surface-constructive (level 3), and knowledge-building activities (level 4 and 5) for conflict and assimilation groups

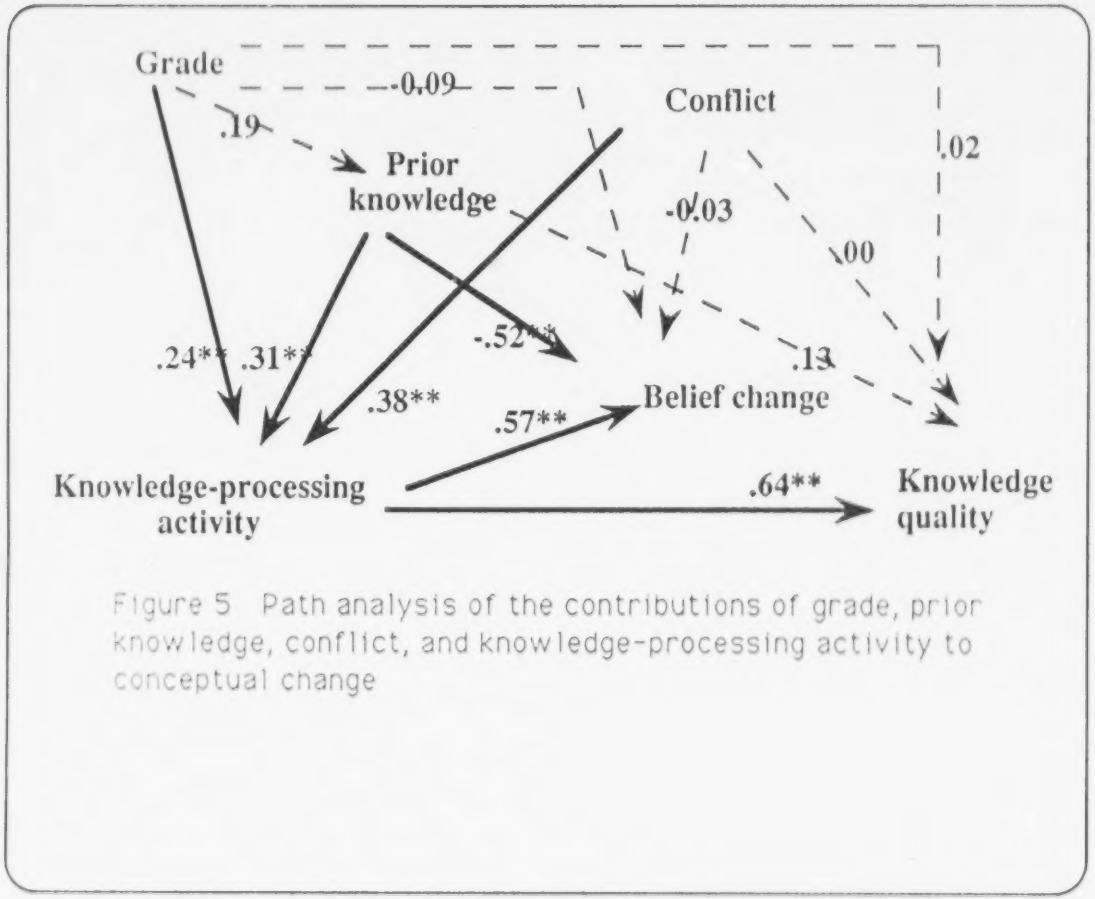


Figure 5 Path analysis of the contributions of grade, prior knowledge, conflict, and knowledge-processing activity to conceptual change